DOI: 10.21857/ypn4oc5qz9
Pregledni članak / Review paper
Prihvaćeno / Accepted: 15. svibnja 2025.

BIOECONOMIC PERSPECTIVES OF FOOD–TECHNOLOGICAL DEVELOPMENT IN THE CONTEXT OF CONTEMPORARY EUROPEAN POLICIES

Tomislav Jurendić

Summary

Nowadays, the agri-food system functions according to a paradox where, as humans, we need food to live, but the way food is produced threatens the potential for food production. In other words, a transformation of the food system, which includes production, processing, distribution, retailing and consumption, is needed in order to respect human and planetary health. One of the possibilities of transformation is a more significant application of the principles of bioeconomy, i.e., circular economy, as defined by contemporary European policies, and as shown in this paper at the example of the chokeberry, as a model for other fruit and vegetable crops, but also more widely. A high-value powder rich in bioactive molecules such as polyphenols can be produced from chokeberries, and the pomace as by-product can be used in the production of snack products. Furthermore, the seeds can be used to obtain chokeberry oil, and the leaves to isolate valuable bioactive compounds. It was also shown how a by-product such as hazelnut shell, which is normally thrown into the environment as worthless raw material, can be effectively used as a soil improver around chokeberry bushes, although there are other possibilities for its use. At the core of this approach is a form of innovation that implies the production of high-value added products; it includes constant changes in the constituent parts of the food system (technology, infrastructure, skills and abilities), and a fundamental reshaping of the values, regulations, policies, markets and management that surround it. This approach as a systemic process implies that food technologies alone are not sufficient to initiate transformations of the food system, and instead ought to be accompanied by a wide range of social and institutional factors that enable their application. Furthermore, this method promotes a holistic approach, enabling the application of natural technologies necessary for achieving the goal. The holistic approach is manifested in the fact that in the search for solutions, it is necessary to keep in mind a more comprehensive view and to find and offer a complete solution, taking into account all aspects (technical, technological, legislative, environmental, etc.) that are indispensable on the way from research and development to the market. Currently, food production is at a crossroads between maintaining the status quo, for which there exist many interested parties, who make large profits, on the one hand, and a radical transformation promoted by a number of powerful interest groups, which, among other things, includes significant changes in eating habits, on the other hand. The shift towards the application of bioeconomic principles, as an alternative to both approaches, is in this paper illustrated by the example of chokeberry. Since transformation itself is a deeply political process, involving choices, consensus and compromise regarding new directions of development, considerable efforts need to be made in order to clarify the meaning of adoption, especially of emerging technologies, for the society as a whole.

Keywords: chokeberry; bioeconomy; European policies; food technology; emerging technologies.

1. INTRODUCTION

Production and consumption in the food industry burdens the global ecosystem considerably. While ensuring sufficient food production and access for all people remains a top priority for the humanity, transition to more sustainable processes should now take precedence [1]. Food production, distribution and consumption are closely related to ecosystems and environmental resources [2]. Food consumption is increasing as the world population grows, putting enormous pressure on natural resources, including air, soil, water and energy [3]. The food industry can play a key role in preserving biodiversity and creating a more sustainable future for the society as a whole by transitioning to environmentally friendly production methods [4]. The adoption of the circular economy concept can be a key component of ecological sustainability in the food industry [5]. The circular economy model prioritizes reuse, recycling and regeneration when designing products and processes to minimize waste and maximize resource efficiency [6]. In the context of the food industry, this refers to the reduction of food waste, the reuse of residues and by-products, and the promotion of recyclable or compostable packaging [7]. Sustainable procurement methods can also greatly reduce the environmental impact of intensive agricultural practices while promoting healthier ecosystems [8]. The food industry can help create a more sustainable ecosystem by applying and adopting bioeconomic principles and the circular economy.

In 2023, the European Commission proposed setting legally binding targets for reducing food waste that the member states ought to achieve by 2030. More specifically, member states must take the necessary measures by the end of 2030 to reduce food waste by 10% in processing and production, and by 30 % (per inhabitant) total in retail sales and consumption (restaurants, catering services and households).

In order to achieve the above aim, the joint action of all interested parties is necessary, respecting the appropriate legislative framework and applying new scientific knowledge. Successfully implemented scientific research projects in this area, which, as a result, have developed prototype products ready for market placement, can be one of the possible ways of reaching the set goals.

Trends in the modern food industry indicate that some companies research, develop and produce food where there is almost no waste in the production process or its amounts are negligible. By-products, food industry waste and food discarded during distribution and consumption are increasingly used as substrates for the biotechnological production of valuable products or as raw material in food production. The latest bioprocesses of by-product processing are intended for the production of nanoparticles, bio preservatives, edible and smart components for food packaging, enzymes, nutraceuticals and food additives, such as polyphenols, vitamins, aroma-components, biosurfactants, exopolysaccharides, bioactive peptides, probiotics and prebiotics [9].

The objective of this paper is to show, using a concrete example from practice, how by applying modern scientific knowledge in research and development, and in partnership with Croatian scientific and research organizations, innovative food products with higher added value can be developed, respecting bioeconomic principles and guidelines on the circular economy, the national strategic framework and modern technological achievements. In addition, the goal is to point out the need for the responsible use of emerging technologies, with a comprehensive approach to the mentioned topic.

2. BIOECONOMY AND FOOD TECHNOLOGY

Bioeconomy or bio-based economy is defined in the narrower sense as an innovative economy with a low level of emissions, in order to ensure the sustainability of agriculture and fisheries, the security of food supply and the sustainable use of renewable biological resources (biomass) in the industry while simultaneously protecting biodiversity and the environment [10].

Bioeconomy implies the production of renewable biological resources and the transformation of these resources and waste materials into products with higher added value, while at the same time limiting the negative impact on the environment. Within the economy, the bioeconomy is observed through the production of biomass and the conversion of biomass into products with added value, such as pharmaceuticals, food and beverages, functional molecules, biofuels or electrical and thermal energy (Figure 1) [11]. In the modern bioeconomy, biomass is used efficiently, cascaded and sustainably, including residues, by-products and waste. As regards food, examples of the main topics [12] in the field of bioeconomy are: anaerobic digestion of food waste to create circular economy [13], food waste systems and life cycle assessment in circular economy [14], circular economy approaches based on bio sciences [15], consumer behavior and attitudes towards circular economy [16], food supply chain and food waste in circular economy [17], material flow analysis and sustainability [18], challenges, policies and practices to achieve circularity [19], and circular economy and consumption patterns [20].

As early as in 2012, the European Union determined the direction through the bioeconomy strategy [10], where priority in the use of biomass is given to products with higher added value through cascade use. At the same time, circular economy is of exceptional importance as an economic model that aims at reducing the use of resources and achieving low carbon levels and a low impact on the environment, by reducing the generation of waste and preserving resources (raw materials, energy and water) [12]. Interest in the bioeconomy furthermore emerges from societies' concerns regarding meeting the increased demand for food through agriculture that more sustainably uses natural resources and reduces the potential for negative environmental impacts [21]. The transformation towards more sustainable and equitable food systems seeks to provide healthy and nutritious food for all, while creating livelihood opportunities and reducing negative impacts [22]. Innovative research in the agriculture and food sectors is transforming food systems through both the increased provision of food and more nutritious and healthy food. The increased provision of safe, nutritious food has life-long health benefits, whereby it contributes to reduced healthcare system expenses [23]. For these purposes, food technology can come to its full potential.

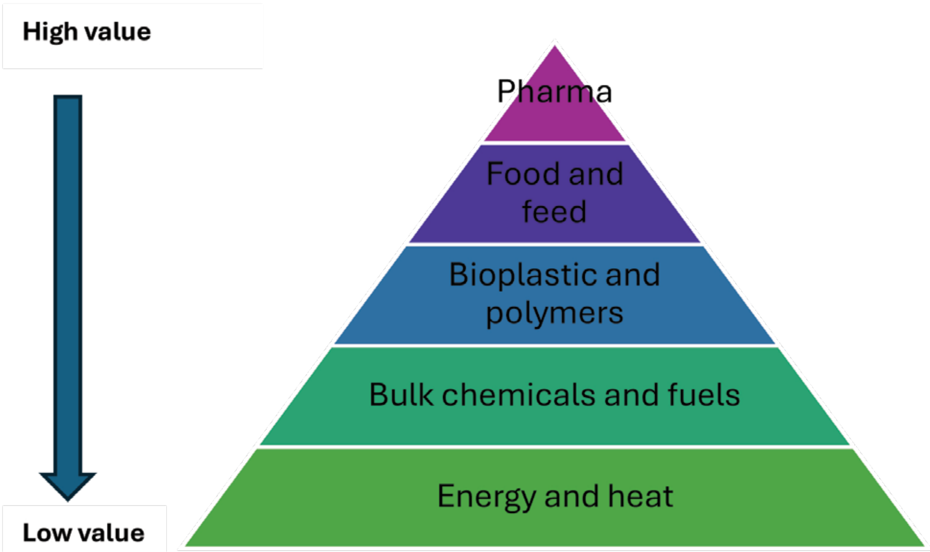

Figure 1. Value pyramid of biomass products (adapted) [11]
Slika 1. Piramida vrijednosti proizvoda biomase (prilagođeno)

According to the definition of the Institute of Food Technologists (IFT – Institute of Food Technologists, 1964), food technology is the application of science and engineering in the production, processing, packaging, distribution, preparation and use of healthy and nutritionally valuable food [24]. There are different approaches to defining food technology, but it is certainly one of the accepted ones that food technology represents a hybrid of food science and food engineering (Figure 2).

Food science is an applied scientific discipline that deals with the chemical, biochemical, physical, physicochemical and biological properties of food. Chemical properties refer to the composition, chemical reactions during production, packaging, storage and interaction of food ingredients with supplements (additives), packaging, equipment, etc. Biochemical properties refer to physiological changes in food due to the action of enzymes, vitamins or other substances. Physical properties include rheological properties such as viscosity, texture, consistency, then density, color and thermal properties. Physicochemical properties include phenomena in dispersed systems, while biological properties refer to the activities of different microorganisms [24].

Food engineering, which became an academic discipline around 1950, is a multidisciplinary scientific field related to food production that covers the practical applications of food science. The purpose of food engineering is to implement effective industrial processing in the conversion of raw materials and materials of biological origin into edible forms for humans, which includes packaging, storage and distribution. Food engineering refers to the study of engineering properties and compositions such as boiling point or freezing point; physical characteristics such as size, shape, volume, surface area, density and porosity; mechanical properties such as compressive, impact and shear strength; sensory properties such as texture and color; and thermophysical properties such as specific volume, specific heat, thermal conductivity, and viscosity. Today's research leaders in the field of food engineering are usually specialists with knowledge in the field of food science and in the areas of materials science (e.g. rheology, properties of substance and heat transfer, etc.), applied mathematics and modeling, and biochemical engineering applied to food. Food engineers also participate in the development of computer techniques as tools for process automation, management, design and improvement [25]. Minimal food processing technologies such as the application of UV-C light (wavelengths of 240–260 nm), ultrasound (28.5–40.5 kHz), pulsed energy, pulsed electric field, pulsed magnetic field and pulsed light, radiation with low doses of gamma rays, high hydrostatic pressure and barrier technology can significantly affect the extension of shelf life of food products [26]. Nowadays, food engineers are increasingly preoccupied with the establishment of such processes in order to produce safe, natural and healthy food products.

Since food consists of a large number of physically, chemically and biologically complex materials, it is necessary to know disciplines such as biochemistry, microbiology and food chemistry at the micro level, i.e., at the macro level, technological operations, thermodynamics, rheology and especially the phenomena of heat, mass and momentum transfer. Modern food technology, as a scientific field in which science and engineering are applied in the production, processing, packaging, distribution, preparation and use of food, is directed to cooperation with other scientific areas, i.e., scientific fields and branches such as agriculture (raw materials for food industry), biotechnology (raw materials for the food industry such as vitamins, enzymes, etc.), microbiology (food safety), mathematics (mathematical modeling of food processes, etc.), informatics (informatics tools for production and business processes), mechanical engineering (production of devices, tools and equipment, heating and cooling systems), electrical engineering (automation of individual or collective technological processes), architecture (design of new plants), civil engineering (plant statics, water supply and drainage systems), law (legislative aspects of production and installation market), logistics (transportation to warehouses and shops in wholesale and retail), marketing, accounting, finance, etc. Therefore, the field of food technology should be viewed more as an interdisciplinary and multidisciplinary field, considering the knowledge that is needed in order for some food-technological process to take place in an effective, efficient and productive way.

Figure 2. Food technology as a combination of food science and food engineering (adapted) [24]
Slika 2. Prehrambena tehnologija kao kombinacija znanosti o hrani i prehrambenog inženjerstva (prilagođeno)

3. FOOD TECHNOLOGY IN STRATEGIC DOCUMENTS

3.1. Strategies

In addition to bio-economic aspects, it is important to observe the determinants of food technology in the context of the strategic framework that is currently valid and, in some way, determines the state's attitude towards future food-technological development. Strategic determinants are very important regardless whether they are scientific research, development, technological or other innovative projects on the one hand, or investments in production facilities and equipment on the other. As concerns the aforementioned framework, it is easy to see what the state's priorities are and what the state intends to achieve in this sense in the future.

The National Development Strategy of the Republic of Croatia until 2030 states that the priority is to increase the efficiency and added value of agricultural production and aquaculture, greater investments in research and development in the agri-food sector, aquaculture and bioeconomy, the integration of farmers into food and agricultural value chains, more efficient use of agricultural land and its management, and provision of higher and more stable incomes for small producers [27]. The strategic plan of the Common Agricultural Policy 2023–2027 states that every day numerous technologies are becoming available for the use of by-products of food production, which too are food and can be used for the production of high-quality products, such as the isolation of biologically valuable components, etc., which opens up additional possibilities market and business expansion, and/or cooperation with other areas of the bioeconomy [28].

The strategy for agriculture until 2030 [29] contains a vision and a plan for the strategic transformation of the sector not only at the level of agricultural operations, but also considering challenges, opportunities and participants that affect the wider agri-food sector, including agricultural production, processing, distribution of products, market and consumer demands ("farm to fork"). Technological development in genetics, nanotechnology, remote research, traceability (blockchain), (big) data analysis, Internet of Things, artificial intelligence, robotics, e-commerce, etc., offers opportunities for production growth, cost reduction, risk reduction, increase in added values and the development of new markets for the Croatian agricultural and food sector. Digital technologies have considerably reduced the costs of sharing information, implementing transactions in agri-food chains, and systems of knowledge and innovation. The necessity of encouraging the establishment of stronger links between scientific and research institutions and the agricultural and food sector, and of directing larger private investments in basic and applied research has been stated too. Although the food processing sector is technologically relatively strong, the overall situation in terms of innovation lags significantly behind other EU countries. Croatia lags behind significantly in agricultural and food research and development, with investments at the level of one third of the average investment per capita in the EU. There is support offered in the form of tax credits for research, development and innovation within companies. The promotion of innovation partnerships was also highlighted, where support will be provided to public-private innovation partnerships that include manufacturers, consultants, agricultural companies and scientific institutions. Partnerships will be established to follow an interactive bottom-up innovation model, where scientific institutions would focus on solving problems and challenges faced by manufacturers.

The Smart Specialization Strategy until 2029 [30] lists Sustainable and Circular Food (Figure 3) as one of the Thematic Priority Areas (TPP), whereby smart specialization is an approach that complements horizontal innovation policies (general framework conditions) with vertical and specific policies aimed at facilitating the creation critical mass in a diversified ecosystem [31]. Sustainable and circular food consists of food production, food processing and services that support production. This TPP aims at improving the sustainability and circularity of industries, i.e., at the transition from a linear to a sustainable and circular model of the food chain. Unfortunately, only 1% of research and development in higher education institutions is financed by companies, and cooperation between SMEs and universities is low (4% of SMEs in Croatia cooperate with universities, in contrast to 10% in the EU). Although Croatia has a long-standing tradition in food production, in some areas it lags significantly behind world production trends.

The strategy states that the Croatian food sector lacks adequate access to sophisticated technologies in the field of food packaging and processing. Therefore, in the development of highly nutritious, healthy, minimally processed, functional and sustainable food products, the application of innovative food processing and packaging techniques and food control and safety is necessary.

Other strategies touch the field of food technology to either a greater or a lesser extent. However, given the purpose and objective of this paper, they are not specifically considered here.

<table>
<tr><th colspan="2">S3 2016 – 2020</th><th>S3 2029</th></tr>
<tr><td>TPA</td><td>PTPA</td><td>TPA</td></tr>
<tr><td rowspan="3">Health and quality of life</td><td>Pharmaceuticals, biopharmaceuticals, medical equipment and devices</td><td rowspan="3">Personalized health care</td></tr>
<tr><td>Health services and new preventive methods medicine and diagnostics</td></tr>
<tr><td>Nutrition</td></tr>
<tr><td rowspan="2">Energy and sustainable the environment</td><td>Energy technologies, systems and equipment</td><td rowspan="2">Smart and clean energy</td></tr>
<tr><td>Environmentally acceptable technologies, equipment and advanced materials</td></tr>
<tr><td rowspan="3">Traffic and mobility</td><td>Production of parts and high added values systems for road and rail vehicles</td><td rowspan="3">Smart and green traffic</td></tr>
<tr><td>Environmentally acceptable transport solutions</td></tr>
<tr><td>Intelligent transport systems and logistics</td></tr>
<tr><td rowspan="3">Security</td><td>Cyber security</td><td rowspan="3">Security and dual purpose – awareness, prevention, response, remediation</td></tr>
<tr><td>Defense technologies and dual-purpose products</td></tr>
<tr><td>Mine countermeasures program</td></tr>
<tr><td rowspan="2">Food and bioeconomy</td><td>Sustainable food production and processing</td><td>Sustainable and circular food</td></tr>
<tr><td>Sustainable wood production and processing</td><td>Customized and integrated wood products</td></tr>
<tr><td>NEW TPA</td><td></td><td>Digital products and platforms</td></tr>
</table>

Figure 3. TPA in the Smart Specialization Strategy [30]
Slika 3. TPP u Strategiji pametne specijalizacije

3.2. Global perspectives and trends

The sale of packaged food at the world level amounts to more than USD 3,000 billion [32]. It is estimated that in the EU, significant amounts of total produced food are lost or wasted, the value of which is estimated at EUR 900 billion in economic costs, with an additional EUR 800 billion in social costs [33.34]. The principles of circular economy have the potential to create 700,000 new jobs and increase the EU's GDP by an additional 0.5% by 2030 [35]. There are significant market opportunities for new product launches, such as fresh food, luxury food, health food and products that emphasize local, organic and sustainable processes [36].

The demand for foods that have potential health benefits exceeding their nutritional value and are often referred to as "functional foods" is growing, as well as for foods that are "sustainably" produced and processed in an effective, efficient and productive manner. Sustainability in agricultural and food systems is not easy to achieve, and a complicating factor is the disagreement in the understanding and use of the term sustainability itself, which was discussed in the introduction.

It is obvious how contemporary EU policies expressed in strategies, action plans and legislative framework support the placing on the market of unprocessed or lightly processed food, produced locally or in a short supply chain, which contain a certain nutritional value with potential health benefits.

3.3. Challenges and opportunities

The current Croatian and European strategies undoubtedly provide a good framework for the use of innovative food-technological solutions in food production; unfortunately, the story ends there somewhere. Experience teaches us that the execution of strategies and all the accompanying documents, such as action plans or similar, is superficially monitored, and there is almost no accountability for the execution or non-execution of the set goals. The lack of support for research, development and innovation in food companies is very pronounced, since most companies have turned to strong investments in marketing, especially product promotion. Some food companies even eliminate sectors such as research and development, and turn to marketing and incremental innovations completely (packaging change for instance), not taking into account the importance of research, development and innovation, knowledge and experience gained during their existence and human capital. As part of tenders from the EU funds, there are individual calls for research, development and innovation, where in principle, there is support for the implementation of projects. They are however often designed in such a way that all companies, from micro and small to medium and large, are classified in the same category, so that small and micro-enterprises are almost unable to pass tenders designed thus.

One of the problems that occur in the area of the food industry, regarding the application of food technologies in food production, is inadequate access to sophisticated processing and packaging technologies. The usual technological processes of processing food are most frequently applied in the Croatian food industry. The application of innovative processing techniques, food packaging and control and food safety is necessary in the development of highly nutritious, healthy, minimally treated, functional and sustainable food products. Traditional methods of packaging in cans and basic plastic packaging are common in the Croatian industry. Considering the durability of plastic and metal packaging, efforts should be made to reduce their use and footprint by developing recycled food packaging materials [30].

Furthermore, there is a lack of knowledge in several steps of the value chain, from research and development, processing and packaging to market research and beyond [30]. In other words, there are not enough educated people in appropriate positions, who could take responsibility and initiate changes. Neither is there a system where the principle of meritocracy is basic, where the establishment of a formal and real management system does not hinder the appointment of the most capable people to the most responsible positions. Therefore, the problem probably does not lie in the quality of knowledge (although there is space for improvement here too), but rather in the impossibility of transferring knowledge into research and development or economic activity.

Furthermore, weak cooperation between scientific research organizations and the business sector is a significant characteristic of the Croatian system [30]. The existing framework does not encourage any cooperation between the scientific community and the economy; it depends on the enthusiasm of individuals on one side or the other. When we talk about the EU funds, some tenders encourage partnerships between scientific research organizations and entrepreneurs, where the conditions for the participation of scientific research organizations are not overly motivating, while on the other hand, the conditions for the participation of entrepreneurs are very strict, and are thus unachievable for most of the Croatian companies. No other incentive framework for cooperation between scientific research organizations and the private sector exists or is unknown to the author.

It is obvious that there is no established system that would support research, development and innovation in the field of food technology, encourage cooperation between scientific research organizations and the private sector, or enable the preservation of acquired knowledge as an identity asset and its further application.

At the food technology level, there are several challenges that need to be solved: research, development and production need to be redirected towards food products with higher added value, with potential health benefits. In doing so, the emphasis should be on horizontal activities and by-products that promote circularity, such as the production of fresh products for the ready-to-eat market and the enjoyment market, products with a targeted composition intended for certain groups, the sustainability of production and processing activities, with a previous unambiguous definition of the term "sustainability", new packaging materials, collection of biological waste and its reuse, adaptation of production and business models, etc.

The above represents an opportunity for mutual cooperation between the scientific research community and companies on innovative projects, which would significantly improve the overall relationship in the triangle of state, the scientific community and the private sector. In modern industrialized societies, the focus on healthy eating has grown significantly in multiple sectors, including the media, public policy, expert opinion, and public awareness [37].

4. CHOKEBERRIES – AN EXAMPLE OF GOOD PRACTICE

Processing chokeberries and its by-product (pomace or even leaf) to the semifinal or final product is an example of good practice and of a practical solution that integrates bio-economic and certain food-technological aspects, knowledge transfer and partnership between the private sector and scientific research organizations. Chokeberry (*Aronia melanocarpa*) is a rose-shaped plant from the Rosaceae family. Since it is an adaptable plant, it has been widespread in our region over the last 15 years. The main characteristic of chokeberry is that it contains increased amounts and a large number of different bioactive molecules (BAM), among which one of the most important are phenolic compounds, to which numerous positive effects on human health or preventive action in the occurrence of various diseases are attributed. The results of the research conducted by Ovaskainen et al. [38] showed that out of 143 different plant samples in which polyphenols were determined, the highest content of these compounds was determined in chokeberry, and they are found in chokeberry by-product extracts too [39]. In addition to polyphenols, chokeberry contains minerals, vitamins, sugars, higher alcohols such as sorbitol, dietary fiber, and other substances.

Chokeberry is additionally interesting because both fruits and leaves can be used for food and pharmaceutical purposes. The fruits are traditionally used for the production of juices, jams and teas, and more recently brandy and wine. Many functional properties, such as antioxidant, anti-inflammatory, antidiabetic, antibacterial, antiviral, antimutagenic, anticarcinogenic and antitoxic properties, are attributed to bioactive chokeberry molecules, i.e., polyphenols. They have a positive effect on hypertension, liver, overweight, thermogenesis, neurodegenerative diseases (dementia, Alzheimer's, Parkinson's), reduction of facial wrinkles, skin whitening, etc. [40].

4.1. Chokeberries

Bioactive chokeberry molecules, polyphenols, i.e., anthocyanins, obtained from organically grown chokeberry fruits, which were identified, quantified, isolated and stabilized in powder form in the frame of the EU funded project Biofracta, implemented within the framework of the call *Increasing the development of new products and services resulting from research and development activities – phase II*, are of interest for this work. Polyphenols are one of the most important antioxidants in the human diet [41, 42]. Chokeberry stands out among various berries as one of the richest sources of polyphenols [43]. The functional properties come primarily from the strong antioxidant effect of polyphenols, which trap free radicals and play a significant role in alleviating certain chronic diseases. The polyphenolic composition of chokeberry undergoes significant changes during fruit development and ripening, whereby unripe fruits show the highest total polyphenol content [44]. Phenolic compounds can be classified in five groups: diferuloylmethane (curcumin), stilbenes, flavonoids, phenolic acids, and tannins. Flavonoids include anthocyanins and anthoxanthins, while anthoxanthins include flavones, flavans, flavanols, and flavonols [45]. Phenolic acids mainly consist of chlorogenic acid and its isomers. Proanthocyanidins have been identified as the primary contributors to the antioxidant activity of chokeberry, given the individual phenolic content of the fruits [46]. Cyanidins, in combination with various glycosides, are the main anthocyanins of chokeberry [47]. Cyanidin-3-O-arabinoside exhibits the most powerful radical scavenging properties among the anthocyanins found in chokeberry, showing strong inhibition of pro-oxidative enzymes [48]. Chokeberry cyanidin-3-O-galactoside shows significantly higher antioxidant capacity compared to other individual anthocyanins. Oral administration of cyanidin-3-O-glucoside and cyanidin-3-O-galactoside resulted in immunomodulatory effects on the functional activity of phagocytes *in vivo* [49]. Cyanidin-3-O-galactoside and caffeoylquinic acid inhibited the release of TNF-α (tumor necrosis factor), interleukin IL-6 and IL-8 in human peripheral monocytes. In addition, chokeberry in synergy with sodium selenite can inhibit NF-κB (nuclear factor-κB) activation, cytokine release and prostaglandin E2 (PGE2) synthesis [50]. Daily intake of 500 mg chokeberry extracts may reduce TC (total cholesterol) and LDL (low-density lipoprotein) levels in smokers. Cholesterol-lowering activity is most closely related to the levels of the methylated metabolites cyanidin-3-O-galactoside and peonidin-3-O-galactoside [51].

There are many other studies that report the specific effects of anthocyanins and phenolic acids, the main bioactive molecules of chokeberry. However, polyphenolic components with strong functional properties needs further systematical identifying. While phenolic compounds are recognized as the primary active components of chokeberries, the specific molecules of chokeberry against diabetes, obesity and neuroprotective agents need further investigation. Further research is also needed to examine ursolic acid (a pentacyclic triterpenoid carboxylic acid), and other constituents of chokeberry fruits that show potential antitumor activity [52]. Additionally, future research on chokeberry should be focused on the optimization of doses of phenolic and other ingredients, the development of new formulations, the isolation of new active compounds, and research into their synthetic modifications. In the future, clinical studies based on a better understanding of the main constituents of chokeberry are needed. There is no doubt that the potential of chokeberry as a potential means for maintaining good general human condition and preventing various diseases is extremely great.

The color of anthocyanidins varies with the number of hydroxyl groups attached to them (especially those substituted in ring B). With the increase of attached hydroxyl groups, the visible color of the molecule changes from orange to purple (Figure 4) [53].

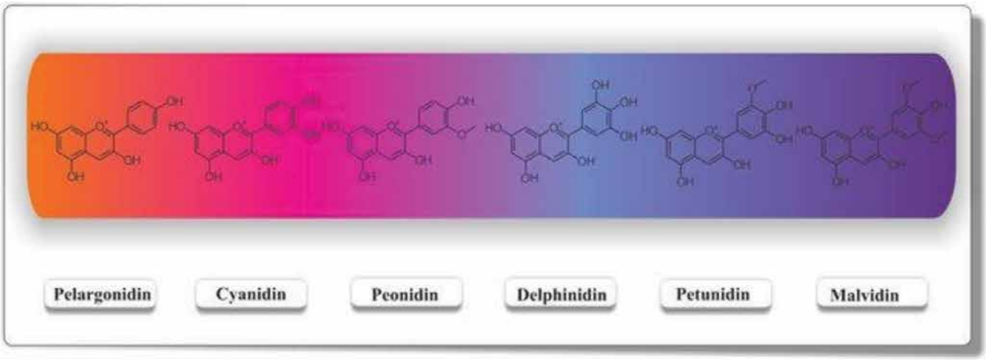

Figure 4. Anthocyanidin color [53]
Slika 4. Boja antocijanidina

Within the mentioned EU project called Biofracta, after identification and quantification, anthocyanins were isolated and translated into powder form; consequently, knowledge and experience from the project were used to produce encapsulated powder that was placed on the market (Figure 5). It is evident that all samples, especially fresh fruits, contain significant mass fractions of phenolic compounds, and the dominant group consists of anthocyanins. After obtaining anthocyanin powder, a part of the tropics, which represents an excellent raw material for innovative products, is left behind in the technological process.

A further EU project, supported by the Rural Development Program, was carried out under the title *Cascaded use of hazelnut and chokeberry by-products in increasing yields and developing new products*. Here the hazelnut shell as by-product was used as soil improver around chokeberry bushes, and the chokeberry pomace as by-product was used as the basis for the production of snack products (Figure 6.). Hazelnut shell makes up more than 50% of the mass of the hazelnut fruit, where the main ingredient is lignin (40–50%), followed by hemicellulose (13–32%) and cellulose (16–27%) [54]. In our own research, hazelnut husks exercised a significant impact on soil quality, where in one year, compared to the previous one, a slight increase in the content of plant nutrients (total nitrogen, accessible forms of phosphorus and potassium) was noticeable in the surface layer of the soil (from 0 to 30 cm), humus, and pH value. Differences in the physical characteristics of the soil were also visible. In the same period, there was a decrease in the average values (averages taken from three repeated samples) of the volume density (from 1.41 to 1.24 g/cm3) and the density of solid particles (from 2.69 to 2.64 g/cm3), and an increase in the percentage of soil porosity (from 47.6 to 53.2 %) and average soil capacity for air (from 8.9 to 10.3 %).

The above results indicate a possible trend of improving the physical properties of the soil, in terms of reducing compaction and increasing the proportion of macropores in the surface layer, which has proved to be very good for chokeberry cultivation.

Figure 5. Encapsulated chokeberry powder
Slika 5. Kapsulirani prah aronije

Figure 6. Snack product made from chokeberry pomace (project: Cascaded use of hazelnut and chokeberry by-products in increasing yields and developing new products)
Slika 6. Snack proizvod od tropa aronije (projekt: Kaskadno korištenje nusproizvoda lješnjaka i aronije u povećanju prinosa i razvoju novih proizvoda)

For the development of the mentioned products, it is necessary to master different knowledge and experience in the use of processing technologies, such as extraction, drying and extrusion. Extraction is defined as the process of extracting a substance from a solid or liquid mixture with a suitable solvent, in which the substance is soluble or has a better solubility than the remaining components of the mixture [24]. Different extraction techniques can be used to extract different phenolic compounds, such as mechanical stirring, ultrasound, homogenization, Soxhlet extraction, maceration, and supercritical fluid extraction [55]. Drying is usually described as the process of thermal removal of volatile substances (moisture) to obtain a solid product [56]. Extrusion is a continuous mechanical and thermal process involving mixing, mechanical cutting and pressure to obtain the desired shape and texture, where various variables such as temperature, moisture, raw material composition, viscosity and mass flow are the most important to obtain an extrudate with good physicochemical properties [57].

4.2. Chokeberry seeds

The seeds belong among the most important components of chokeberry, of which there are between 5 and 7 in the fruit. According to some authors, the oil content is 19.3 g/kg of chokeberry seeds, while phospholipids (2.8 g/kg oil), sterols (1.2 g/kg oil) and tocopherols (55.5 mg/kg oil) are the main components of the oil. Among the phospholipids, the most abundant are phosphatidylinositol (29.8 g/kg), phosphatidylcholine (19.9 g/kg) and phosphatidylethanolamine (16.6 g/kg), while the sterol composition is dominated by β-sitosterol (89.8 g/kg). Of the tocopherols, α-tocopherol (70.6 mg/kg) was identified in the largest amount. Chokeberry oil is rich in polyunsaturated fatty acids, such as linoleic (73.99%), oleic 18.74%, linolenic (0.59%), eicosene (0.14% and palmitoleic (0.1%). The oil contains identified β-carotene (0.015 g/kg) and trace amounts of chlorophyll [58]. There are a large number of papers that indicate that certain fatty acids and other molecules have a positive effect on human health [58, 59, 60, and 61]. Linoleic acid is used in skin care products for restructuring, strengthening, moisturizing and smoothing the skin, and has various anti-inflammatory and antimicrobial properties. It is used in the treatment of atopic eczema, acne and other dermatological conditions, and has a positive effect on hair growth, as well as on the health of the heart and blood vessels. Linolenic acid, important for skin beauty and health, reduces and slows down the appearance of wrinkles, improves the moisture, elasticity and strength of the skin, has an anti-inflammatory effect, and accelerates healing. Phospholipids are important for the development of biochemical functions in the human body and necessary for the regulation of the energy-related cellular functions. Phosphatidylcholine is an essential lipid for liver health and lipoprotein metabolism [62]. Compartmentalization is an indispensable feature of eukaryotic cells, the goal of which is physical and functional binding and differentiation of internal membrane structures. The central role in this process plays the phosphorylated species of phosphatidylinositol phospholipids, the so-called phosphoinositide, which act as key determinants of membrane identity in endocytic and exocytic pathways, also directing signal transduction, vesicular budding and fusion, cytoskeleton dynamics, regulation of integral plasma membrane proteins, endosome and Golgi dynamics functions [63]. Phosphatidylethanolamine (PE) is a multifunctional phospholipid required for mammalian development that is essential for a number of cellular processes. The intrinsic biophysical properties of this lipid induce the formation of hexagonal phases within the membrane and, in this way, promote membrane fusion and fission, protein integration into membranes, and conformational changes in protein structure. PE is the second most abundant phospholipid in the cell, accounting for 15–25% of total phospholipids in mammalian cells. However, PE is not only a passive component of the membrane; it functionally relates to protein biogenesis and activity, oxidative phosphorylation, autophagy, membrane fusion, mitochondrial stability, and is an important precursor of other lipids [64]. Sterols are present in all eukaryotes and perform essential functions within the cell membrane [65]. Phytosterols, steroid compounds including plant stanols and sterols, have a similar structure to cholesterol. They are believed to reduce the concentration of cholesterol in the plasma by reducing the intestinal absorption of cholesterol, increasing the expression of LDL receptors in the liver, and reducing the production of endogenous LDL-cholesterol [66]. The synergistic action of the aforementioned functional molecules of chokeberry oil ought to be further investigated and confirmed within the framework of new projects, especially clinical research.

4.3. Chokeberry leaf

According to available literature data, chokeberry leaf contains various bioactive substances such as chlorogenic acid, its isomers, caffeic acid, quercetin-3-O-glucopyranoside and rutin [67]. Young chokeberry leaves also contain neochlorogenic acid [68]. Chokeberry leaf extract strongly inhibits the generation of peroxide radicals *in vitro*, and significantly reduces CCl_4-induced hepatic lipid peroxidation *in vivo* [69]. Chokeberry leaves can be effective in the prevention and treatment of cancer, leukemia and other chronic diseases [70]. Chokeberry leaf extract is known to participate in reducing the number of human leukemia cells, HL60 cells and human myeloid leukemia cells; this is believed to be a consequence of the action of polyphenolic compounds contained in chokeberry leaf extract [70]. Some research results show that chokeberry leaf extract can inhibit the growth and inflammation of cancer cells [71].

From the above brief description of the potential positive effects of chokeberry and its extracts on health, it is evident that this plant contains a large number of different chemical compounds in significant quantities, which, with regular intake into the body, can contribute to the preservation and improvement of human health and the improvement of the general condition. In this sense, it is necessary to find appropriate food-technological solutions in order to preserve the mentioned bioactive substances in their original form and in the largest possible quantities, applying the valid EU and Croatian strategic and legislative framework.

5. PERSPECTIVES OF FOOD TECHNOLOGY DEVELOPMENT

Nowadays, the agri-food system functions according to a paradox where, as humans, we need food to live, but the way food is produced threatens the potential for food production. In other words, a transformation of the food system, which includes production, processing, distribution, retailing and consumption, is needed in order to respect human and planetary health [72]. One of the possibilities of transformation is the application of the principles of bioeconomy, i.e., circular economy, as demonstrated by the example of chokeberry processing, as a model for other fruit and vegetable crops and beyond. In short, a high-value powder of polyphenols can be produced from chokeberry, and the pomace can be used as a by-product for the production of snacks. Furthermore, the seeds can be used to obtain chokeberry oil, and the leaves to isolate valuable natural compounds. It was also shown how a by-product, such as hazelnut shell, which is normally thrown into the environment as a worthless raw material, can be effectively used as a soil improver, although there are other possibilities for its use. At the heart of this approach lies a form of innovation that involves constant changes in the constituent parts of the food system (technologies, infrastructure, skills and capabilities), and a fundamental reshaping of the values, regulations, policies, markets and governance that surround it.

This approach as a systemic process implies that food technologies alone are not sufficient to initiate transformations of the food system, but that they ought to be accompanied by a wide range of social and institutional factors that enable their application instead. Furthermore, this method promotes a holistic approach, enabling the application of natural technologies necessary to achieve the goal. The holistic approach is manifested in the fact that, in the search for solutions, it is necessary to keep in mind the larger picture, and find and offer a complete solution, taking into account all aspects (some of which were mentioned earlier) of importance on the way from research to the market. In this sense, focusing on food technology only will not help much; it is necessary to look at all vertical and horizontal aspects that affect the achievement of the desired goals.

Today, there are other initiatives in the agri-food sector, i.e., in the field of application of food and other technologies, which, according to some authors, could potentially solve various challenges of the agri-food system. Accordingly, different solutions in different areas are researched, developed and offered, individually or collectively:

- Cellular agriculture (artificial meat/fish, artificial products, molecular printing);
- Digital agriculture (advanced sensors, artificial intelligence, assistive exoskeletons, big data, data integration, pest/disease early warning, drones, farm-to-farm virtual marketplace, improved climate forecasting, intelligent food packaging, Internet of Things, nano-drones, nanotechnology, omic data use, on-field robots, pest control robotics, pre-birth sex determination, robotics, soil sensors, SERS (surface-enhanced Raman scattering) sensors, smartphone food diagnostics, traceability technologies, tracking/confinement technology for livestock);
- Food processing and safety (biodegradable coatings, drying/stabilization technologies, food safety technologies, microorganisms coating, nanocomposites, sustainable processing technologies, whole genome sequencing);

- Genetic technologies (apomixis, biofortified crops, disease/pest resistance, genome editing, genome wide selection, GM-assisted domestication, novel nitrogen-fixing crops, novel perennials, oils in crop, plant phenomics, reconfiguring photosynthesis, RNAi gene silencing, synthetic biology, weed competitive crops);
- Health (personalized food);
- Inputs (botanicals, enhanced efficiency fertilizers, holobiomics, macrobials, micro-irrigation/fertigation, microbials, nanoenhancers, nanofertilizers, nanopesticides, soil additives);
- Intensification (electro-culture, irrigation expansion, vertical agriculture);
- Other (3D printing, battery technologies, ecological biocontrol, resurrection plants);
- Alternative feed (dietary additives for livestock, innovative aquaculture feed, insects for food, livestock/seafood substitutes, microalgae and cyanobacteria for food, microbial proteins, omega-3 products for aquaculture and seaweed as feed) [73].

All of the mentioned technologies are currently in various stages of readiness for use, from those in the research and experimental development phase, to others in the prototype development and application phase. Regardless of that, in the Republic of Croatia, at a strategic level, a critical review of the aforementioned emerging technologies, which in some international circles have great support for their application, is needed. Since transformation is a deeply political process, involving choices, consensus, and compromise regarding new directions, considerable effort is needed to interpret what the adoption of emerging technologies means for the society as a whole. One part of the powerful players within the food system have strong incentives to maintain the status quo and their current market share, while the others have strong incentives to change and apply the aforementioned technologies. Without excluding one or the other, perhaps natural food technologies with the application of bioeconomic principles are a possible solution in future food production.

6. CONCLUSION

Currently, food production is at a crossroads between maintaining the status quo, for which there exist many interested parties, who make large profits, on the one hand, and a radical transformation promoted by a number of powerful interest groups, which, among other things, includes significant changes in eating habits, on the other hand. The shift towards the application of bioeconomic principles, as an alternative to both approaches, is illustrated by the example of chokeberry in this paper. What is our point of view, what will we do as a society and which option will we opt for? These complex challenges require a holistic approach and additional extensions in the future, as well as continuous monitoring of changes in all segments.

References

1. Agnusdei, GP, Coluccia, B. Sustainable Agrifood Supply Chains: Bibliometric, Network and Content Analyses, *Sci. Total Environ.*, *824*, 2022, 153704.
2. Maclean, K, Cuthill, M, Ross, H. Six Attributes of Social Resilience, *J. Environ. Plan. Manag.*, *57*, 2014, 144–156.
3. Fan, S, Brzeska, J. Feeding More People on an Increasingly Fragile Planet: China's Food and Nutrition Security in a National and Global Context, *J. Integr. Agric.*, *13*, 2014, 1193–1205.
4. Simsek, EK, Kara, M, Kalıpçı, MB, Eren, R. Sustainability and the Food Industry: A Bibliometric Analysis, *Sustainability,* 16, 2024, 3070, https://doi.org/10.3390/su16073070.
5. Korhonen, J, Honkasalo, A, Seppälä, J. Circular Economy: The Concept and Its Limitations, *Ecol. Econ.*, 143, 2018, 37–46.
6. Moreau, V, Sahakian, M, Van Griethuysen, P, Vuille, F. Coming Full Circle: Why Social and Institutional Dimensions Matter for the Circular Economy, *J. Ind. Ecol.*, 21, 2017, 497–506.
7. Ng, BJH, Mao, Y, Chen, C-L, Rajagopal, R, Wang, J-Y. Municipal Food Waste Management in Singapore: Practices, Challenges and Recommendations, *J. Mater. Cycles Waste Manag.*, 19, 2017, 560–569.
8. Mustofa, MA, Suseno, BD, Basrowi, B. Technological Innovation and the Environmentally Friendly Building Material Supply Chain: Implications for Sustainable Environment, *Uncertain Supply Chain Manag.*, 11, 2023, 1405–1416.
9. Kos, B, Novak, J, Leboš Pavunc, A, Banić, M, Butorac, K, Čuljak, N, Šušković J. Proizvodnja i inkaspulacija sljedeće generacije probiotika i njihovih bioaktivnih molekula primjenom nusproizvoda prehrambene industrije. *In: Neke mogućnosti iskorištenja nusproizvoda prehrambene industrije - Book 5,* Chapter 1, 1-27, eds.: Šubarić, D, Jašić, M, Jokić, S, 2024.
10. Europska komisija. Innovating for Sustainable Growth: A Bioeconomy for Europe, 60, Bruxelles, *COM* 2012.
11. Kulišić, B. Bioekonomija, *Sektorske analize*, 74, 9, Ekonomski institut Zagreb, Zagreb, 2020.
12. Tamasiga, P, Miri, T, Onyeaka, H, Hart, A. Food Waste and Circular Economy: Challenges and Opportunities. *Sustainability*, 14, 2022, 9896, https://doi.org/10.3390/su14169896.

13. Pérez-Camacho, MN, Curry, R, Cromie, T. Life cycle environmental impacts of substituting food wastes for traditional anaerobic digestion feedstocks, *Waste Manag.*, 73, 2018, 140–155.
14. Kowalski, Z, Kulczycka, J, Makara, A, Harazin, P. Quantification of material recovery from meat waste incineration–An approach to an updated food waste hierarchy, *J. Hazard. Mater.*, 416, 2021, 126021.
15. Jagtap, S, Garcia-Garcia, G, Duong, L, Swainson, M, Martindale, W. Codesign of Food System and Circular Economy Approaches for the Development of Livestock Feeds from Insect Larvae, *Foods*, 10, 2021, 1701.
16. Borrello, M, Caracciolo, F, Lombardi, A, Pascucci, S, Cembalo, L. Consumers' Perspective on Circular Economy Strategy for Reducing Food Waste, *Sustainability*, 9, 2017, 141.
17. Dora, M, Biswas, S, Choudhary, S, Nayak, R, Irani, Z. A system-wide interdisciplinary conceptual framework for food loss and waste mitigation strategies in the supply chain, *Ind. Market. Manag.*, 93, 2021, 492–508.
18. Teigiserova, DA, Hamelin, L, Thomsen, M. Review of high-value food waste and food residues biorefineries with focus on unavoidable wastes from processing, *Resour. Conserv. Recycl.*, 149, 2019, 413–426.
19. McCarthy, B, Kapetanaki, AB, Wang, P. Circular agri-food approaches: Will consumers buy novel products made from vegetable waste? *Rural. Soc.*, 28, 2019, 91–107.
20. Fogarassy, C, Nagy-Pércsi, K, Ajibade, S, Gyuricza, C, Ymeri, P. Relations between Circular Economic "Principles" and Organic Food Purchasing Behavior in Hungary, *Agronomy*, 10, 2020, 616.
21. Wesseler, J, von Braun, J. Measuring the bioeconomy: economics and policies. *Ann Rev Resour Econ* 9, 2017, 17.1–17.24.
22. von Braun, J, Afsana, K, Frescom, L, Hassan, M, Torero, M. Food systems– definition, concept and application for the UN Food Systems Summit. Scientific Group for the UN Food Systems Summit, 2020.
23. Trigo, E, Chavarria, H, Pray, C, Smyth, SJ, Torroba, A, Wesseler, J, Zilberman, D, Martinez, JF. The Bioeconomy and Food Systems Transformation In: *Science and Innovations for Food Systems Transformation,* Springer Nature Switzerland AG, Cham, Switzerland, 2023.
24. Lovrić, T. *Procesi u prehrambenoj industriji s osnovama prehrambenog inženjerstva*, HINUS, Zagreb, 2003.
25. Barbosa-Cánovas GV, Juliano P. Food Engineering In: *Encyclopedia of Life Support Systems (EOLSS)*, EOLSS Publishers Co. Ltd., Oxford, UK, 2009.

26. Piližota, V. Fruits and Vegetables (Including Herbs). In: *Food Safety Management, A Practical Guide for the Food Industry, Sec. Ed.* (Eds. Andersen, V, Huub, L, Motarjemi, Y.), ACADEMIC PRESS, San Diego, California, CA, United States, 235-268, 2023.
27. The government of the Republic of Croatia, *National development strategy of the Republic of Croatia until 2030,* 2021.
28. The government of the Republic of Croatia, *Strategic Plan of the Common Agricultural Policy of the Republic of Croatia 2023 - 2027*, Zagreb, 2021.
29. The government of the Republic of Croatia, *Strategy of agriculture until 2030*, Zagreb, 2021.
30. The government of the Republic of Croatia, *Strategy of smart specialization until 2029*, Zagreb, 2023.
31. Foray, D, David, PA, Hall, B. Smart Specialisation - The Concept, Knowledge Economists Policy Brief no. 9. Available at: *kfg_policy_brief_no9.pdf (europa.eu*), 2009.
32. FAO. The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems, Rome, 2023, https://doi.org/10.4060/cc7724en.
33. European Commission. New action plan for circular economy, For a cleaner and more competitive Europe, *COM (2020)* 98 final, Bruxelles, 2020.
34. SAPEA (Science Advice for Policy by European Academies). A sustainable Food System for the European Union. *Evidence Review Report* n.7., 2020.
35. European Commission. A New Circular Economy Action Plan, *Vol. COM/2020/98 final*, 2020.
36. Lord, S. Hidden costs of agrifood systems and recent trends from 2016 to 2023 – Background paper for The State of Food and Agriculture 2023, *FAO Agricultural Development Economics Technical Study*, No. 31. Rome, FAO, 2023.
37. de Moraes Prata Gaspar, MC, Soar, C, Aguilera, M, Gomez, MC, Celorio-Sardà, R, Comas-Basté, O, Vidal-Carou, MC. What Is Considered Healthy Eating? An Exploratory Study among College Students of Nutrition and Food Science, *Nutrients*, 16, 2024, 1365, https://doi.org/10.3390/nu16091365.
38. Ovaskainen, ML, Törrönen, R, Koponen, JM, Sinkko, H, Hellström, J, Reinivuo, H, Mattila, P. Dietary Intake and Major Food Sources of Polyphenols in Finnish Adults, *The Journal of Nutrition*, 2008, 562-566.
39. Elez Garofulić, I, Repajić, M, Zorić, Z, Jurendić, T, Dragović-Uzelac, V. Evaluation of Microwave- and Ultrasound-Assisted Extraction Techniques for Revalorization of Black Chokeberry (*Aronia melanocarpa*) Fruit Pomace Anthocyanins, *Sustainability,* 15, 2013, 7047, https://doi.org/10.3390/ su15097047.

40. Go, MY, Kim, J, Jeon, CY, Shin, D.W. Functional Activities and Mechanisms of Aronia melanocarpa in Our Health, *Curr. Issues Mol. Biol.*, 46, 2024, 8071–8087, https:// doi.org/10.3390/cimb46080477.
41. Rana, A, Samtiya, M, Dhewa, T, Mishra, V, Aluko, R.E. Health Benefits of Polyphenols: A Concise Review, *J. Food Biochem., 46*, 2022, e14264.
42. Shen, N, Wang, T, Gan, Q, Liu, S, Wang, L, Jin, B. Plant Flavonoids: Classification, Distribution, Biosynthesis, and Antioxidant Activity, *Food Chem. 383*, 2022, 132531.
43. Staszowska-Karkut, M, Materska, M. Phenolic Composition, Mineral Content, and Beneficial Bioactivities of Leaf Extracts from Black Currant (*Ribes nigrum* L.), Raspberry (*Rubus idaeus*), and Aronia (*Aronia melanocarpa*), *Nutrients*, *12*, 2020, 463.
44. Yang, H, Kim, Y, Shin, Y. Influence of Ripening Stage and Cultivar on Physicochemical Properties and Antioxidant Compositions of Aronia Grown in South Korea, *Foods*, *8*, 2019, 598.
45. Han, X, Shen, T, Lou, H. Dietary polyphenols and their biological significance, *International Journal of Molecular Sciences,* 8(9), 2007, 950-988.
46. Chen, L, Chen, W, Li, D, Liu, X. Anthocyanin and Proanthocyanidin from *Aronia melanocarpa* (Michx.) Ell.: Purification, Fractionation, and Enzyme Inhibition, *Food Sci. Nutr.*, *11*, 2023, 3911–3922.
47. Denev, P, Ciz, M, Kratchanova, M, Blazheva, D. Black Chokeberry (*Aronia melanocarpa*) Polyphenols Reveal Different Antioxidant, Antimicrobial and Neutrophil-Modulating Activities, *Food Chem.*, 284, 2019, 108–117.
48. Tan, H, Cui, B, Zheng, K, Gao, N, An, X, Zhang, Y, Cheng, Z, Nie, Y, Zhu, J, Wang, L, Shimizu, K, Sun, X, Li, B. Novel Inhibitory Effect of Black Chokeberry (*Aronia melanocarpa*) from Selected Eight Berries Extracts on Advanced Glycation End-Products Formation and Corresponding Mechanism Study, *Food Chem. X*, 21, 2023, 101032.
49. Bushmeleva, K, Vyshtakalyuk, A, Terenzhev, D, Belov, T, Nikitin, E, Zobov, V. Aronia melanocarpa Flavonol Extract-Antiradical and Immunomodulating Activities Analysis, *Plants*, 12, 2023, 2976.
50. Appel, K, Meiser, P, Millan, E, Collado, JA, Rose, T, Gras, CC, Carle, R, Munoz, E. Chokeberry (Aronia melanocarpa (Michx.) Elliot) Concentrate Inhibits NF-kappaB and Synergizes with Selenium to Inhibit the Release of Pro-Inflammatory Mediators in Macrophages, *Fitoterapia*, 105, 2015, 73–82.
51. Xie, L, Vance, T, Kim, B, Lee, SG, Caceres, C, Wang, Y, Hubert, PA, Lee, J, Chun, OK, Bolling, BW. Aronia Berry Polyphenol Consumption Reduces Plasma Total

and Low-Density Lipoprotein Cholesterol in Former Smokers without Lowering Biomarkers of Inflammation and Oxidative Stress: A Randomized Controlled Trial, *Nutr. Res.*, 37, 2017, 67–77.

52. Khwaza, V, Aderibigbe, BA. Potential Pharmacological Properties of Triterpene Derivatives of Ursolic Acid, *Molecules*, 29, 2024, 3884, https://doi.org/10.3390/ molecules29163884.
53. Ananga, A, Georgiev, V, Ochieng, J, Phills, B, Tsolova, V. Production of Anthocyanins in Grape Cell Cultures: A Potential Source of Raw Material for Pharmaceutical, Food, and Cosmetic Industries, In: *The mediterranean Genetic Code – Grapewine and Olive*, 2013.
54. Puliga, F, Leonardi, P, Minutella, F, Zambonelli, A, Francioso, O. Valorization of Hazelnut Shells as Growing Substrate for Edible and Medicinal Mushrooms, *Horticulturae*, 8, 2022, 214, https://doi.org/10.3390/ horticulturae8030214.
55. Flais, D, Oroian, M. Extraction of Bioactive Compounds from Oxheart Tomato Pomace (Lycopersicon esculentum L.) Using Different Solvents: Characterization of Extracts, *Appl. Sci.*, 14, 2024, 7143, https://doi.org/10.3390/ app14167143.
56. Mujumdar AS, Menon A.S. Drying of Solids: Principles, Classification, and Selection of Dryers, In: *Handbook of Industrial Drying*, 2nd edition, vol. 1, Mujumdar, A.S., Marcell Dekker, Inc., New York, Basel, 1995.
57. Huang, Y, Liu, L, Sun, B, Zhu, Y, Lv, M, Li, Y, Zhu, X.A. Comprehensive Review on Harnessing Soy Proteins in the Manufacture of Healthy Foods through Extrusion, *Foods*, 13, 2024, 2215, https://doi.org/10.3390/ foods13142215.
58. Zlatanov, M.D. Lipid composition of Bulgarian chokeberry, black currant and rose hip seed oils, *Journal of the Science of Food and Agriculture*, 79 (12), 1999, 1620-1624.
59. Kapoor, B, Kapoor, D, Gautam, S, Singh, R, Bhardwaj, S. Dietary polyunsaturated fatty acids (PUFAs): Uses and potential health benefits, *Curr. Nutr. Rep.*, *10*, 2021, 232–242.
60. Bajramova, A, Spégel, P. A Comparative study of the fatty acid profile of common fruits and fruits claimed to confer health benefits, *J. Food Compos. Anal.*, *112*, 2022, 104657.
61. Calder PC. Omega-3 fatty acids and inflammatory processes: from molecules to man, *Biochem Soc Trans.*, 45(5), 2017, 1105–15.
62. Weigand, K, Peschel, G, Grimm, J, Höring, M, Krautbauer, S, Liebisch, G, Müller, M, Buechler, C. Serum Phosphatidylcholine Species 32:0 as a Biomarker for Liver Cirrhosis Pre- and Post-Hepatitis C Virus Clearance, *Int. J. Mol. Sci.*, 25, 2024, 8161, https://doi.org/10.3390/ ijms25158161.

63. Kourkoulou, A, Martzoukou, O, Fischer, R, Amillis, S. Atype II phosphatidylinositol-4-kinase coordinates sorting of cargo polarizing by endocytic recycling, *Communications Biology*, 7, 2024, 855.
64. Calzada, E, Onguka, O, Claypool, SM Phosphatidylethanolamine Metabolism in Health and Disease, *Int Rev Cell Mol Biol.,* 321, 2016, 29–88.
65. Brunoir, T, Mulligan, C, Sistiaga, A, Vuu, KM, Shih, PM, O'Reilly, SS, Summons, RE, Gold, D.A. Commonorigin of sterol biosynthesis points to a feeding strategy shift in Neoproterozoic animals, *Nature Communications*, 14, 2023, 7941.
66. Han, S., Jiao, J., Xu, J., Zimmermann, D., Actis-Goretta, L., Guan, L., Zhao, Y. & Qin, L. Effects of plant stanol or sterol enriched diets on lipid profiles in patients treated with statins: systematic review and meta analysis, *Scientific Reports*, 6, 2016, 31337, doi: 10.1038/srep31337.
67. Borowska, S, Brzóska M.M. Chokeberries (*Aronia melanocarpa*) and their products as a possible means for the prevention and treatment of noncommunicable diseases and unfavorable health effects due to exposure to xenobiotics, *Comp Rev Food Sci Food Safety*, 15, 2016, 982-1017.
68. Thi, ND, Hwang, E.S. Bioactive compounds contents and antioxidant activity in aronia (Aronia melanocarpa) leaves collected at different growth stages, *Prev Nutr Food Sci,* 19(3), 2014, 204-212.
69. Denev, P, Kratchanova, M, Ciz, M, Lojek, A, Vasicek, O, Blazheva, D, Nedelcheva, P, Vojtek, L, Hyrsl, P. Antioxidant, antimicrobial and neutrophil-modulating activites of herb extracts, *Acta Biochim Pol.* 61(2), 2014, 359-367.
70. Skupie, K, Kostrzewa-Nowak, D, Oszmianski, J, Tarasik, J. *In vitro* antileukaemic activity of extracts from chokeberry (*Aronia melanocarpa* [Michx] Elliot) and mulberry (*Morus alba* L.) leaves against sensitive and multidrug resistant HL60 cells, *Phytother Res*., 22(5), 2008, 689-694.
71. Thi, ND, Hwang, E.S. Anti-cancer and anti-inflammatory activities of aronia (Aronia melanocarpa) leaves, *Asian Pacific Journal of Tropical Biomedicine*, 8(12), 2018, 586-592, doi: 10.4103/2221-1691.248095.
72. van Zanten, HHE, Maindl, TI, Simon, W, Frehner, A, van Selm, B, Wacker, J, Hijbeek, R, van Ittersum, MK, Herrero, M. Circularity in Europe strengthens the sustainability of the global food system, *Nature Food,* 4, 2023, 320-330.
73. Herrero, M, Thornton PK, Mason-D'Croz, D, Palmer, J, Benton GT, Bodirsky, BL, Bogard JR, Hall, A, Lee, B, Nyborg, K, Pradhan, P, Bonnett, GD, Bryan, BA, Campbell, BM, Christensen, S, Clark, M, Cook, MT, de Boer IJM, Downs, C, Dizyee, K, Folberth, C, Godde, CM, Gerber, JS, Grundy, M, Havlik, P, Jarvis, A, King, R,

Loboguerrero, AM, Lopes, MA, McIntyre, CL, Naylor, R, Navarro, J, Obersteiner, M, Parodi, A, Peoples, MB, Pikaar, I, Popp, A, Rockström, J, Robertson MJ, Smith, P, Stehfest, E, Swain, SM, Valin, H, van Wijk, M, van Zanten, HHE, Vermeulen, S, Vervoort, J, West, P.C. Innovation can accelerate the transition towards a sustainable food system, *Nature Food* 1, 2020, 266–272.

BIOEKONOMSKE PERSPEKTIVE PREHRAMBENO-TEHNOLOŠKOG RAZVOJA U KONTEKSTU SUVREMENIH EUROPSKIH POLITIKA

Sažetak

U današnje vrijeme poljoprivredno-prehrambeni sustav funkcionira prema paradoksu gdje kao ljudi trebamo hranu za život, ali način proizvodnje hrane ugrožava potencijal za proizvodnju hrane. Drugim riječima, potrebna je transformacija prehrambenog sustava, koja obuhvaća proizvodnju, preradu, distribuciju, maloprodaju i potrošnju, kako bi se poštivalo ljudsko i planetarno zdravlje. Jedna od mogućnosti transformacije je značajnija primjena načela bioekonomije, odnosno kružnog gospodarstva, kako to definiraju suvremene europske politike, a kako je u ovome radu pokazano na primjeru aronije, kao modela za druge voćarske i povrtlarske kulture, ali i šire. Naime, iz bobica aronije se može proizvesti visokovrijedni prah bogat bioaktivnim molekulama, poput polifenola, a trop se kao nusproizvod može koristiti za proizvodnju snack proizvoda. Nadalje, iz sjemenki se može dobiti ulje aronije, a iz listova izolirati vrijedni bioaktivni spojevi. Pokazano je također, kako se jedan nusproizvod, kao što je ljuska lješnjaka, koja se u pravilu odbacuje u okoliš kao bezvrijedna sirovina, može učinkovito koristiti kao poboljšivač tla oko grmova aronije, iako postoje i druge mogućnosti njezine primjene. U središtu ovog pristupa je oblik inovacije koji podrazumijeva proizvodnju proizvoda veće dodane vrijednosti, a uključuje stalne promjene u sastavnim dijelovima prehrambenog sustava (tehnologija, infrastruktura, vještine i sposobnosti) i temeljno preoblikovanje vrijednosti, propisa, politika, tržišta i upravljanja koji ga okružuju. Ovaj pristup kao sustavni proces implicira kako prehrambene tehnologije same po sebi nisu dovoljne za pokretanje transformacija prehrambenog sustava te umjesto toga, moraju biti praćene širokim rasponom društvenih i institucionalnih čimbenika koji omogućavaju njihovu primjenu. Također, ovaj način promovira holistički pristup, omogućavajući primjenu prirodoskladnih tehnologija potrebnih za postizanje cilja. Holistički pristup se očituje u tome kako je u potrazi za rješenjima potrebno imati u vidu širu sliku te pronaći i ponuditi cjelovito rješenje, vodeći računa o svim aspektima (tehničkim, tehnološkim, zakonodavnim, okolišnim i dr.) koji su neizostavni na putu od istraživanja i razvoja do tržišta. Trenutačno se proizvodnja hrane nalazi na raskrižju između zadržavanja postojećeg stanja, za što postoji velik broj zainteresiranih aktera, koji ostvaruju velike profite, s jedne strane, i radikalne transformacije koju promiču brojne moćne interesne skupine, koje, između ostalog uključuje značajne promjene u prehrambenim navikama, s druge strane. Pomak prema primjeni bioekonomskih principa, kao alternativa navedenim pristupima, u ovom radu je ilustriran na primjeru aronije. Budući da je transformacija sama po sebi dominantno politički proces, koji uključuje izbore, konsenzus i kompromis o novim smjerovima razvoja, potrebno je uložiti značajne napore kako bi se pojasnilo značenje prihvaćanja, posebice tehnologija u nastajanju, za društvo u cjelini.

Ključne riječi: aronija; bioekonomija; europske politike; prehrambena tehnologija; tehnologije u nastajanju.

Tomislav Jurendić
Bioquanta Ltd.
Trg Zlate Bartl 11/A, 48000 Koprivnica, Croatia
E-mail: tomislav.jurendic@bioquanta.hr